Energy, Power, and Thermal Research Overview

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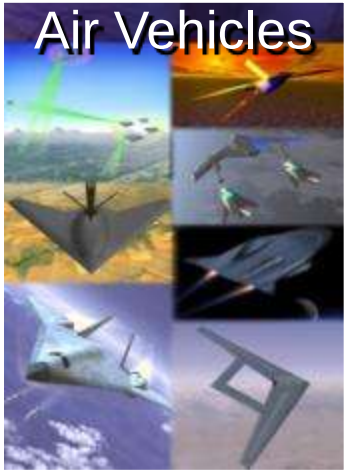
Overview

- AFRL
- Drivers and Applications
- Technologies
- Questions

AFRL Mission

Leading **the discovery, development, and integration of affordable warfighting technologies for our air and space force.**

AFRL's Core Areas of Expertise



AFRL People & Facilities

- 5,764 Government Employees
  - 4570 Air Force Civilian
  - 1194 Military
- 3,844 Onsite Contractors

- 10 Major R&D Sites across US
- 40 Sites World-Wide
- $40B Real Property & Capital throughout AFRL

Propulsion Directorate's Strategic Way Forward

- **RZ Portfolio addresses long-term AF capabilities**
  - Air-breathing High Speed Strike/ISR
  - Energy Security
  - Long Endurance ISR/Mobility
  - Energy Optimized Aircraft
  - Reusable Access to Space
  - Spacecraft Maneuverability

It's An Exciting Time!

TSSS

Hall Thrusters

HC Boost

X-51

Space & Missile

Hypersonics

AIR FORCE RESEARCH LABORATORY

PROPULSION DIRECTORATE

Energy Power & Thermal

Turbines

BRITES

ADVENT

INVENT

FUELS

HEETE

Sustainment

Key Planning Drivers

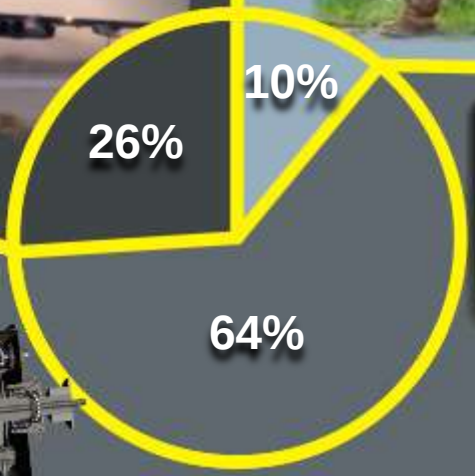
- **Energy**
  - Make energy a consideration in all we do
  - Ensure continued viability of propulsive energy sources
  - Optimize efficiency at the platform level to increase capabilities by minimizing thermal limitations and also to reduce fuel used
- **Thermal**
  - Address today's thermal challenges and prevent tomorrow's thermal limitations
- **System Integration**
  - Deconflict subsystem interactions and define/demonstrate interfaces
- **Infrastructure**
  - Invest in energy, power, and thermal research facilities to establish research foundation for the future

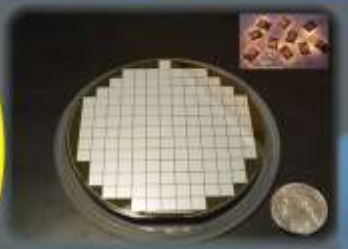
Energy, Power, and Thermal

(FY10-15 from FY11 PBR ~ $54M/year)

Battlespace Fuels

Special Purpose Power

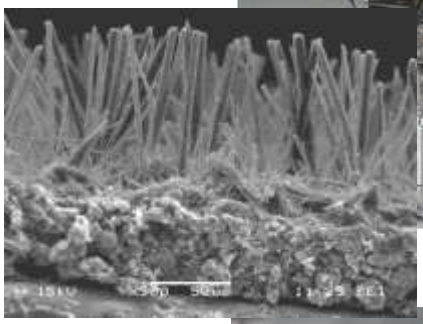


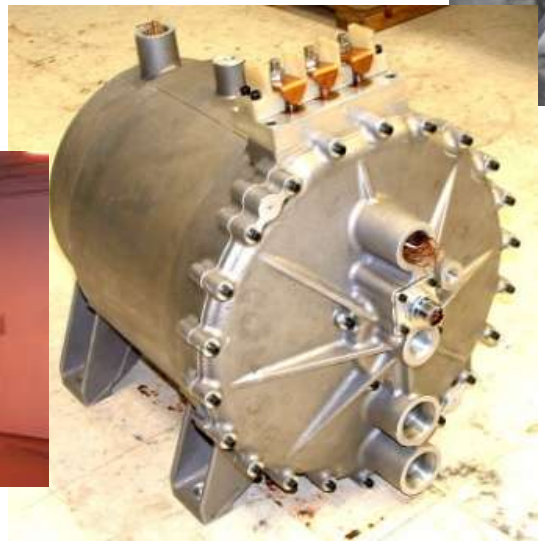


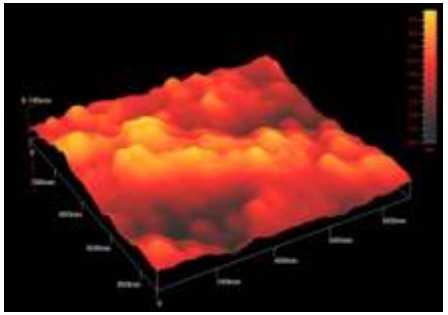
Energy Optimized Aircraft

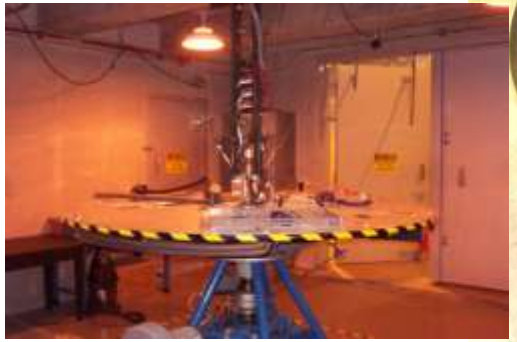
Energy/Power/Thermal Core Technical Competencies

- Power distribution and electronics
- Electrochemistry
- Mechanical energy conversion
- Thermal management
- Fuel utilization and characterization
- System integration and optimization
- Power and thermal analysis and M&S



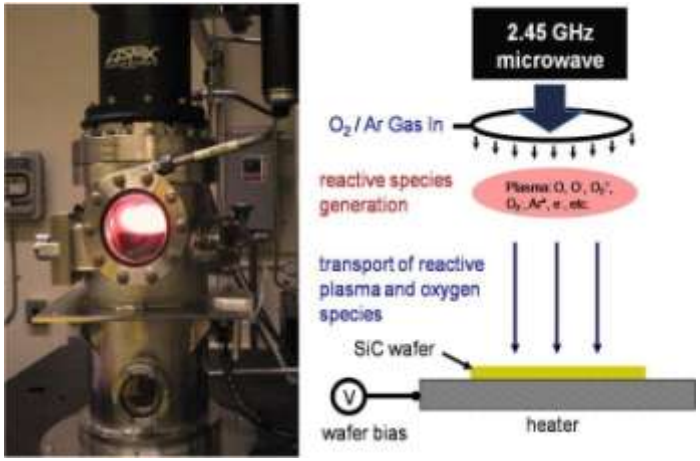




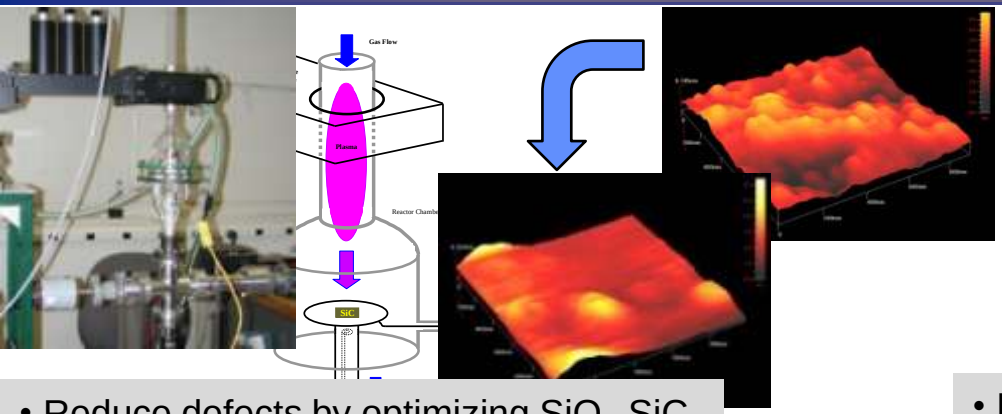


Power Distribution and Electronics

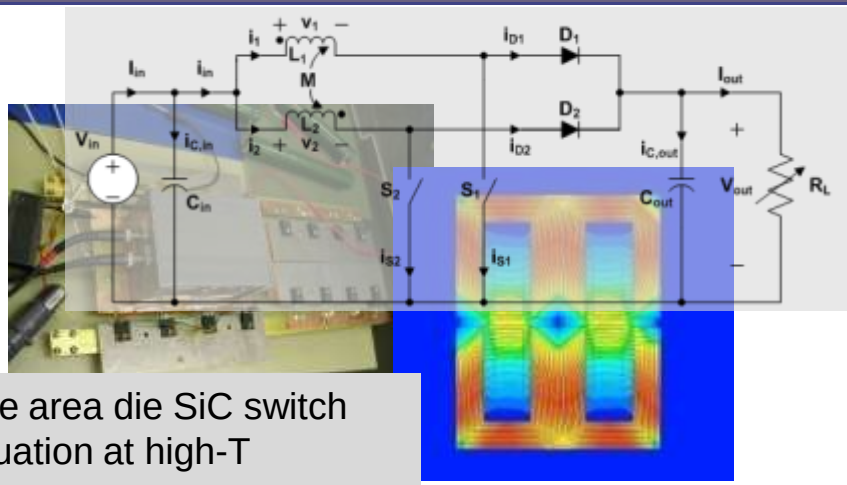
- Performance evaluation and advanced insulations
- Energy storage
- Dielectrics
- Carbon nanotubes for power applications
- SiC device and module reliability
- Plasma physics for defect-free high temperature wide-band gap electronics



Power Distribution and Electronics

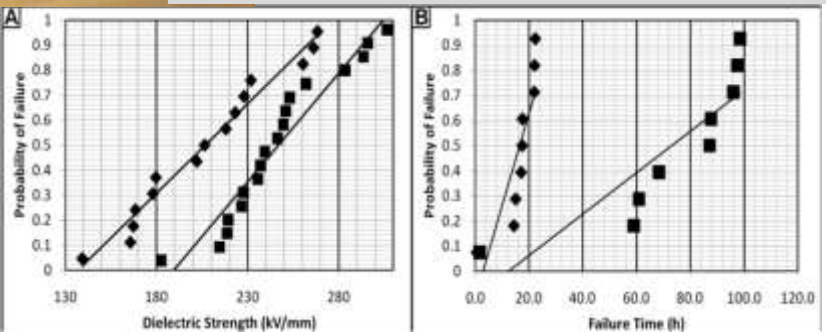


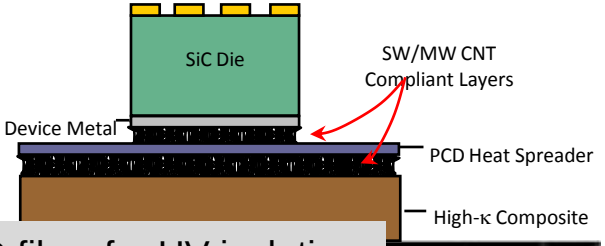
- Reduce defects by optimizing SiO_2-SiC interface using a low-T growth (300°C) process and atomic oxygen to remove C-atom (CO, CO_2)



- Large area die SiC switch evaluation at high-T
- Inductor design comparison

- Effects of EM fields, corona, discharges on aerospace power systems
- High voltage discharge breakdown experiments

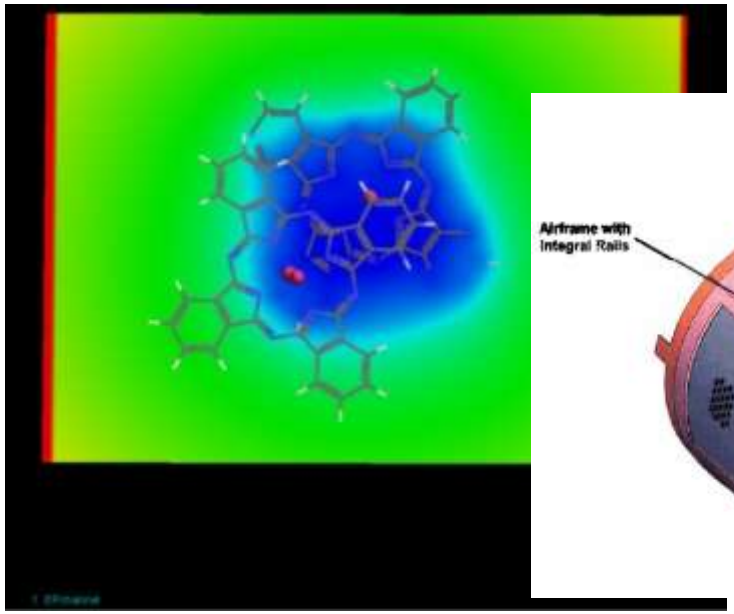


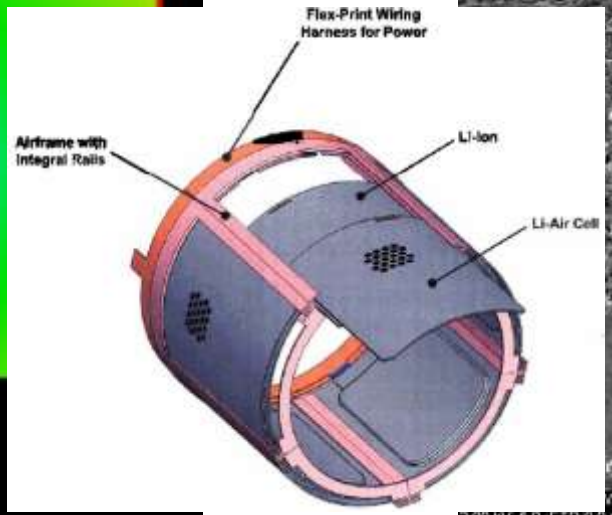


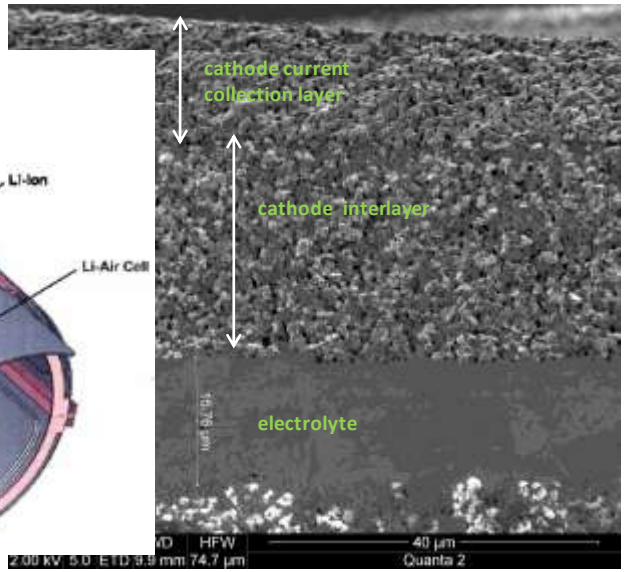
- Demonstrate PCD films for HV isolation and heat spreading layers in high-T power electronic packages
- CNT interface for stress compliancy for CTE_{PCD}~1-2 ppm/K

Electrochemistry

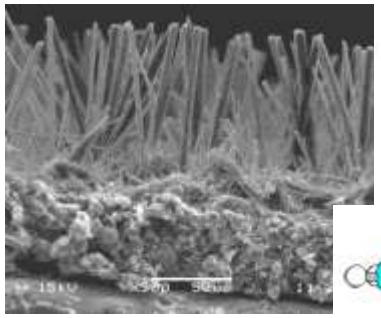
- Solid-state electrolyte for Li-ion batteries
- Li-air chemistries for high performance batteries
- High performance SOFCs
- Battery evaluation and analysis

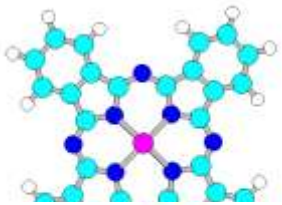


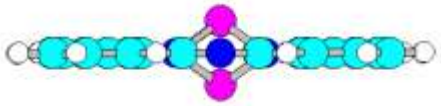




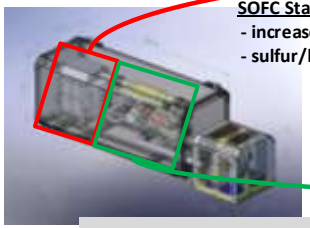
Electrochemistry







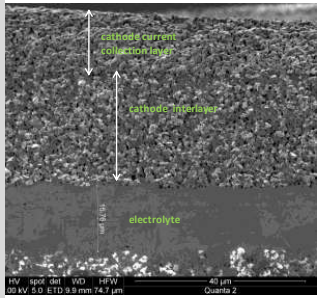
- Develop critical process parameters for scaling solid-state Li-ion batteries
- ab initio calculations model ionic/electronic transport in a “Phthalocyanine Complex”
- Results validated through synthesis processes



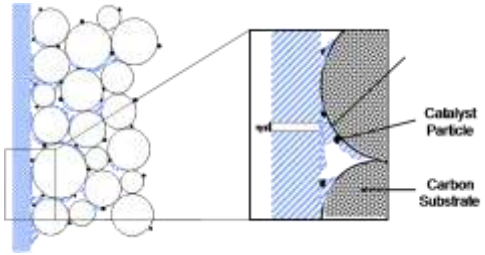
REDUCTION IN STACK WEIGHT/VOLUME

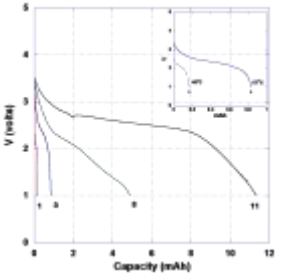
EXPANSION TO JP-8 REFORMATION WITH NEGLIBLE INCREASE IN WEIGHT/VOLUME

- Enable fuel-flexible capabilities to utilize energy-dense logistic fuels for SOFCs
- Optimize functional gradation to reduce interfacial impedance and increase fuel cell power density



- Evaluate and analyze electrochemical power technologies through simulation of mission profiles
  - Investigate problem solution
  - Recommend solutions
  - Solve aircraft systems integration problems

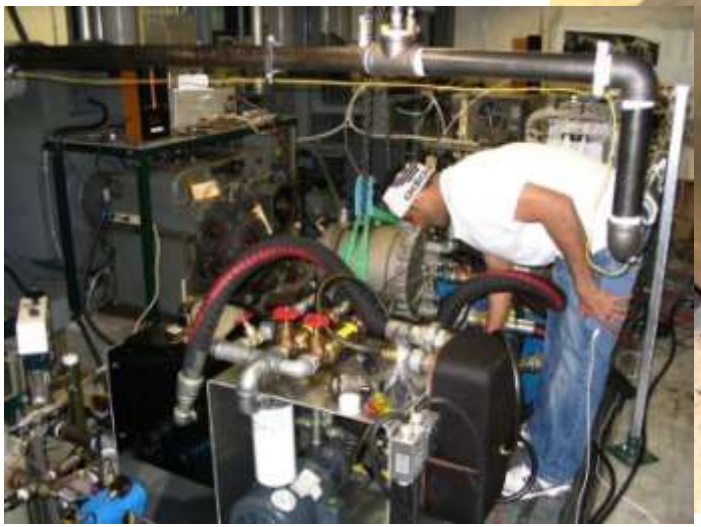




- Li-air chemistries for high performance batteries
  - New cathodic formulations by enhancing triple phase boundaries
  - M&S using classical thermodynamics and chemical species mole balance

Mechanical Energy Conversion

- **High temperature superconductors**
- **Mega-Watt power generation**
- **Magnetic materials**
- **Thermoelectric power generation**

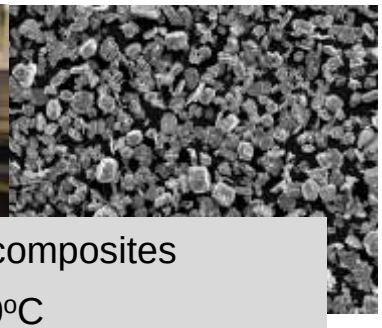


- Mega-Watt power generation
  - Superconducting and conventional generators
  - Short-circuit, open-circuit and low-load endurance testing
  - Used performance results and empirical analysis to modify generator to improve performance

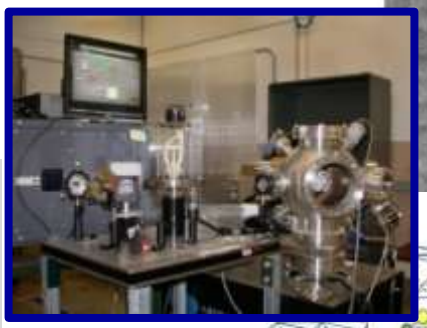
Mechanical Energy Conversion

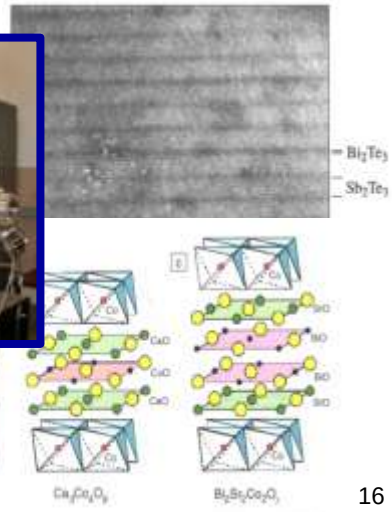
~60#, 12 T
NbTi-Superconductor Magnet

- Develop YBCO superconductor properties for optimal performance
- Produce long lengths of YBCO coated conductors (DC and AC)
  - Minimize ac loss due to high power generation…lower heat loss
  - Stability and quench Issues
  - 1000A – 20,000A power transmission cables - lower weight and heat loss



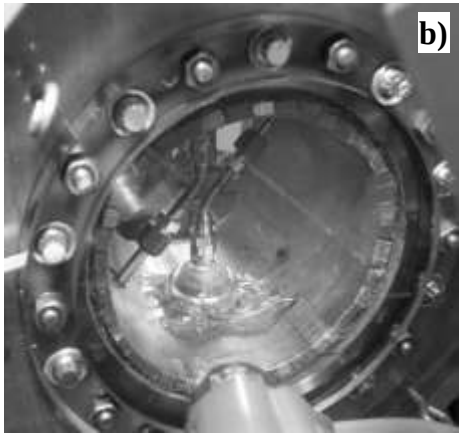
- Soft magnetic material composites
  - High-T up to 500°C
  - Operating frequencies up to 1 MHz
- Hard magnetic materials
  - High-T hybrid systems
  - Exchange spring systems with improved energy products (NdFeB, SmCo/Fe, FeCo)



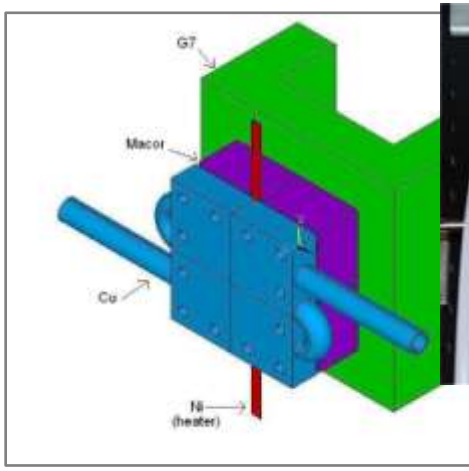


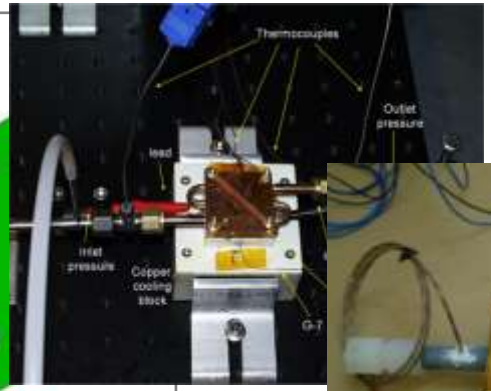
- Multilayered structures for thermoelectric power generation
  - Oxide materials
  - Promote phonon scattering to inhibit thermal flow and increase efficiency
  - Nanostructure dispersions

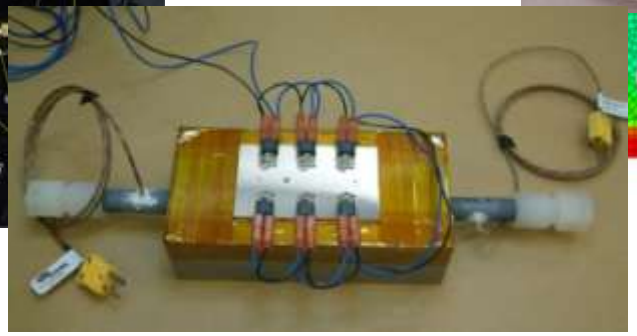
Thermal Management

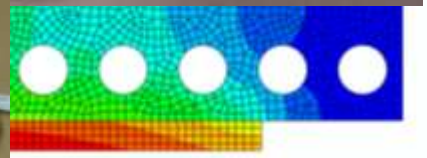


- Thermal management of SiC power modules
- Fuel cooling of turbo machinery
- Loop heat pipe for electronics cooling
- Thermal energy storage for mega-Watt applications
- Vapor cycle technologies for on-demand high-flux cooling applications

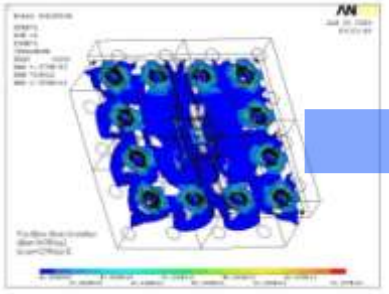


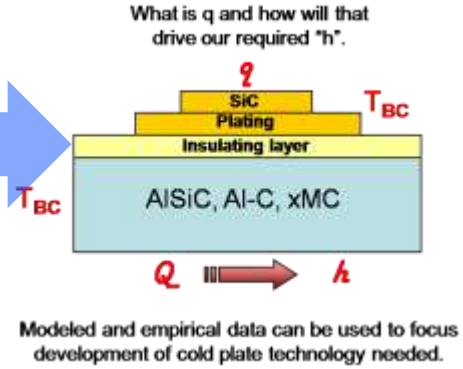






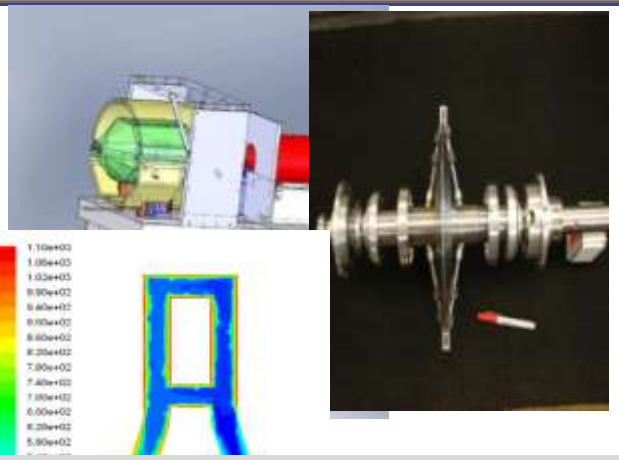
Thermal Management



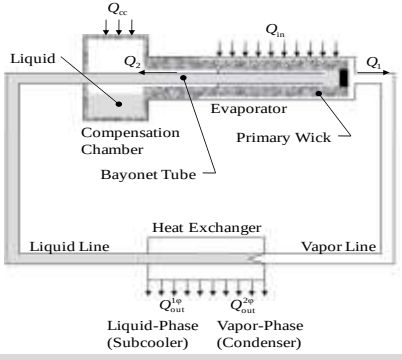


Modeled and empirical data can be used to focus development of cold plate technology needed.

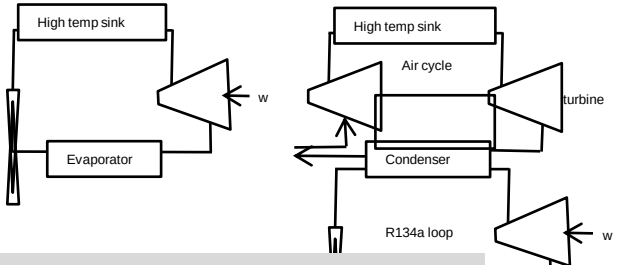
- Investigate and demonstrate SiC packaging technologies, target Rq,jc =0.15cm2K/W
  - Optimize heat transfer
  - Increase temp uniformity
  - Minimize CTE-related stress



- Investigate fuel cooling of rotating turbine components
- Combine experimental and modeling activities to understand fluid dynamics and thermal performance



- Dynamic LHP performance with time variant body forces for electronic component cooling

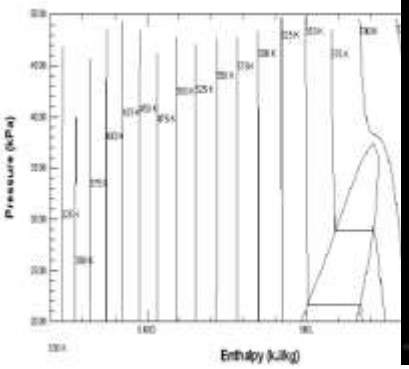


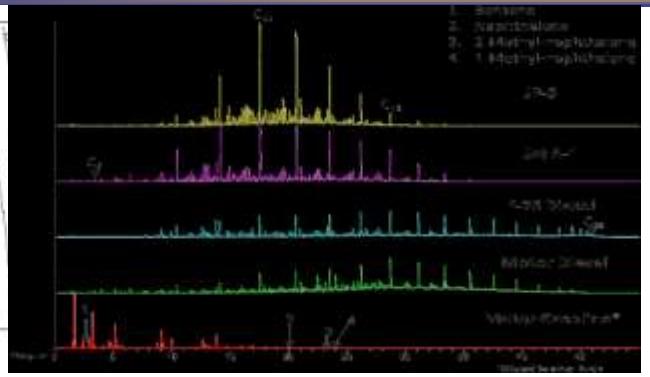
- On-demand VCS for high-flux cooling
- Time-accurate M&S and experimental validation (non-equilibrium physics, theoretical thermodynamics)

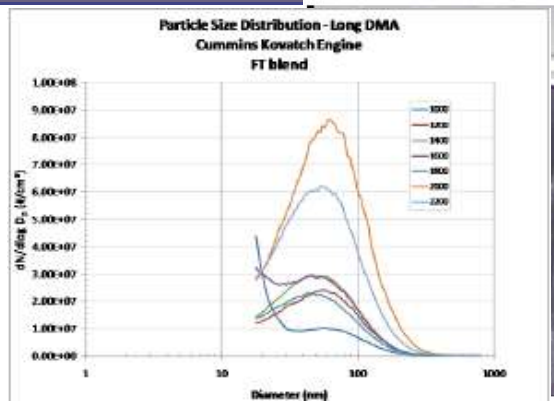
Fuel Utilization and Characterization

- Endothermic fuels and hydrocarbon propellants
- Develop and optimize alternative fuels technologies (AAFRF)
- Microbial activity in fuels
- Emissions reduction via fuel technologies
- M&S of fuels technology
- Fuel characterization and fundamental studies
- Small engine fuel testing
- Nanofuels

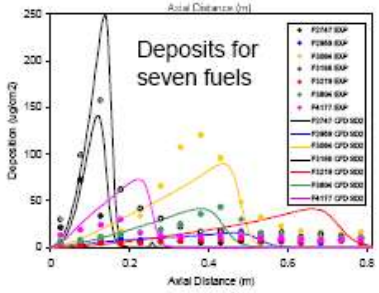
Fuel Utilization and Characterization

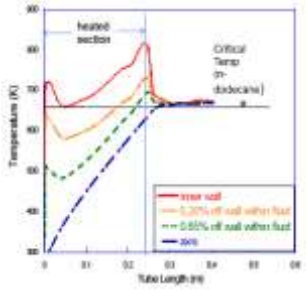






- Develop composition-based physical property models for endothermic fuels
- Thermal-oxidative deposition model enhanced





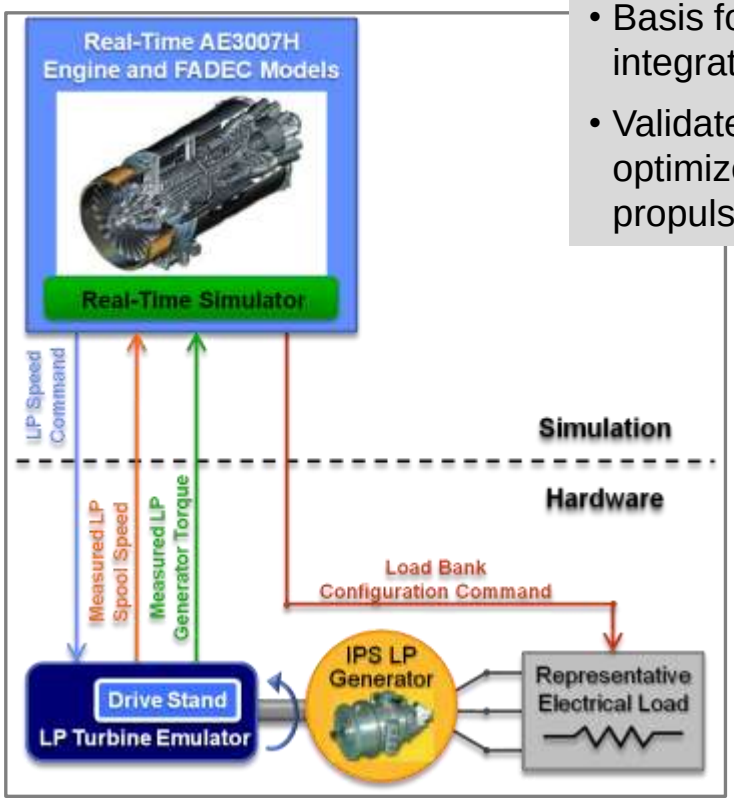
- Fuel system modeling tools for fuel system design
- Realistic heat flows
- Modules for various fuels
- Complex geometries
- Oxidation and deposition

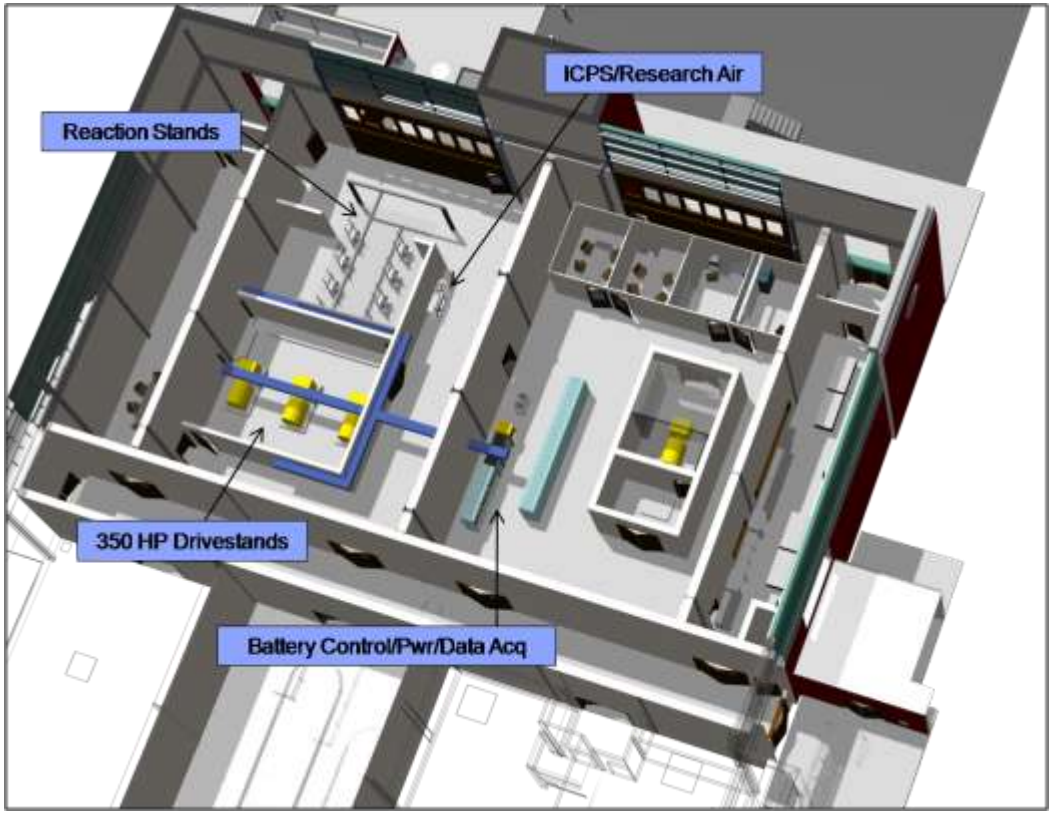
- Emissions evaluation with alternative fuels
  - Research combustor
  - Military and commercial engines
- Conventional techniques
  - Particle size, mass, and number
  - Chemical analysis of particulates
  - Gaseous emissions

- Leverage small engine technologies for alternative and heavy fuels

System Integration and Optimization

- Basis for SIL/HIL approach to system integration and energy optimization
- Validate HIL concepts for SIL approach to optimize power, thermal management, and propulsion from an energy perspective



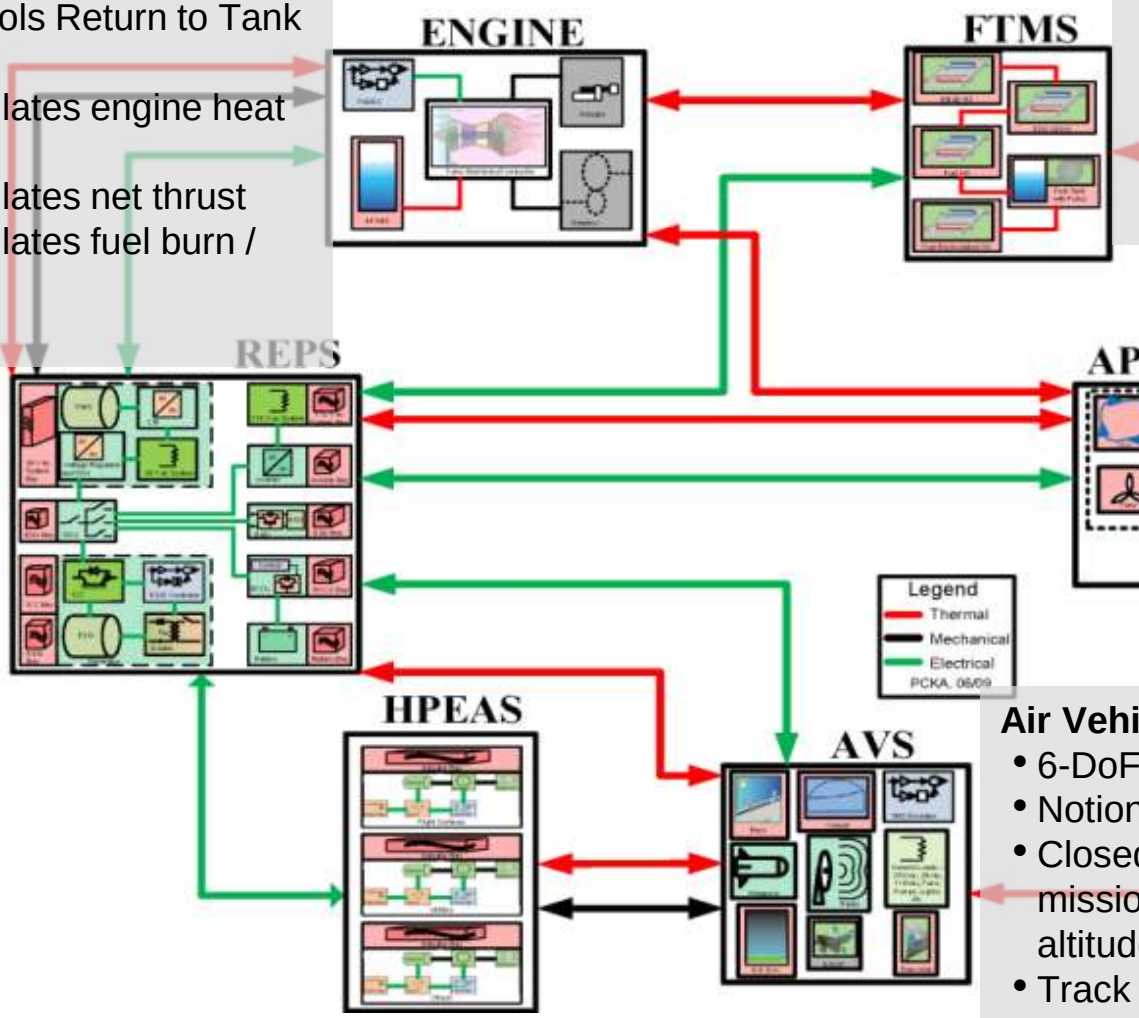


Power and Thermal Analysis and M&S

- **Power and thermal M&S toolset development**
- **Power and thermal component and subsystem modeling**
- **Vehicle system-level modeling "Tip-to-Tail"**
  - Power and thermal technology trades
  - Mission impact/benefits assessments for "energy optimized" vehicle architectures

Power and Thermal Analysis and M&S

Engine (quasi-steady state)
- Controls Return to Tank Flow
- Calculates engine heat loads
- Calculates net thrust
- Calculates fuel burn / SFC



Fuel Thermal Management System (FTMS)
- Fuel mass & temp
- Convection, conduction, radiation
- Ram air HX

Power Thermal Management System (PTMS)
- Air cycle or vapor cycle
- Cold air heat sink
- Heat sink for PAO loop

Air Vehicle System (AVS)
- 6-DoF to vehicle model
- Notional Long Range Strike
- Closed loop control over mission profile (speed, altitude, heading)
- Track metrics (range, endurance, fuel burn)

Summary

- Energy, power, and thermal are inter-related technologies and design considerations
- We investigate fuels, power and thermal devices and components, and system level M&S
- System optimization at the platform level saves energy and addresses thermal limitations
- International collaborations on energy, power, and thermal science and technologies are welcomed and desired

Questions?

Warfighters: Today's and Tomorrow's